FINAL Report for COMET proposal entitled:

"Development of an Automatic Calibration Scheme for Colorado River Basin Forecasts"
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1. Summary of Project Objectives

The goal of this proposal was to further interactions and cooperation with the NWS River Forecast Centers on calibration procedures used in the NWS hydrologic modeling and forecasting system, with special emphasis on the western region basins. The project involved developing an automated procedure for multi-level basins, and aiding in the infusion of calibration technologies into operational forecasting. Aside from the manual calibrations commonly used by hydrologists, several of the RFCs have been attempting to integrate automatic calibration schemes as complementary tools. In the past, single-step, single-criterion calibration schemes were the primary automatic procedures available. These single-step schemes were not adequate in replacing the use of traditional manual calibrations. In order to remedy this dilemma, researchers at the University of California, Los Angeles (UCLA) successfully combined the components of manual and automatic calibration techniques to produce a Multi-Step Automatic Calibration Scheme (MACS) (Hogue et al., 2000). MACS varied from previous automatic routines in its global search algorithm and its ability to mimic NWS calibration procedures through a multi-step approach. MACS utilizes the OPT3 automatic optimization program within the current version of the NWS River Forecast System (NWSRFS). The original PI (Soroosh Sorooshian) on this proposal relocated to the University of California-Irvine (UCI) during the summer of 2003, Dr. Hogue (who was primarily developing and working on this research proposal at the University of Arizona) took over leadership of this project and hence funding was transferred to UCLA to continue the collaborations with CBRFC. The first few months at UCLA involved hiring of a new student to work on the project and set-up and initialization of computer codes, etc. Throughout the length of the project, there was valuable collaboration between UCLA and the forecasting hydrologists at the CBRFC in Salt Lake City, including data exchange, troubleshooting and guidance to the CBRFC on optimization procedures within the operational setting, and successful implementation of automated procedures within the CBRFC.

Specific research objectives of the proposal included: (1) To develop an automated method for calibration of the "multi-tiered" watersheds in western RFCs, (2) Test the developed automatic calibration method on an entire forecast group in the CBRFC region, (3) To operationally test basins calibrated via the automatic procedure, and (4) To test the automatically calibrated water supply forecast points within the ESP verification system. We have successfully completed three of the four objectives in our original proposal, and step four is being evaluated as to its feasibility. The HP platform system currently used by UCLA (accessed through UC-Irvine) is no longer being supported by the NWS, and the transition to the LINUX platform supported system is underway. This transition and setup has caused delay in potentially

implementing the ESP system for the forecast group used in this study. Various outreach and education activities are on-going, including presentations at the CBRFC, scheduled for October of 2005, and various publications to be distributed to RFC hydrologists. A report summarizing results of the study with specific guidelines on implementing the developed procedures and a peer-reviewed journal article are in progress. The report and journal article will be distributed to the 13 RFCs along with the Hydrologic Laboratory of the NWS.

2. Project Accomplishments and Findings

2.1 Overview of Methods and Study Area

The Colorado Basin River Forecasting Center (CBRFC) forecasting region, located in the southwestern United States, contains several major drainages. In consultation with the CBRFC, six basins in the San Juan River system located in Southwest Colorado were chosen for this study. These six basins include three headwater basins: PSPC2 (San Juan River at Pagosa Springs), VCRC2 (Los Pinos River at Vallecito Reservoir), and PIDC2 (Piedra River at Arboles). Additionally, there are three down-stream basins: LOSC2 (Los Pinos River at La Boca), SJCC2 (San Juan River at Carracas), and NVRN5 (San Juan River at Navajo Reservoir). These six basins make up the sub-watersheds of the Upper San Juan River system, meeting and combining flow at the Navajo Reservoir (Figure 1). Tiers or levels are typically established for each watershed by elevation band, usually to adjust to the high alpine, middle alpine and lower elevation areas. The six basins under study range in size and elevation bands; the largest basin approximating 2204.5 square kilometers and three tiers. The range of size in the study basins and the inclusion of levels in the various basins allow the MACS application to be tested over a larger set of data.

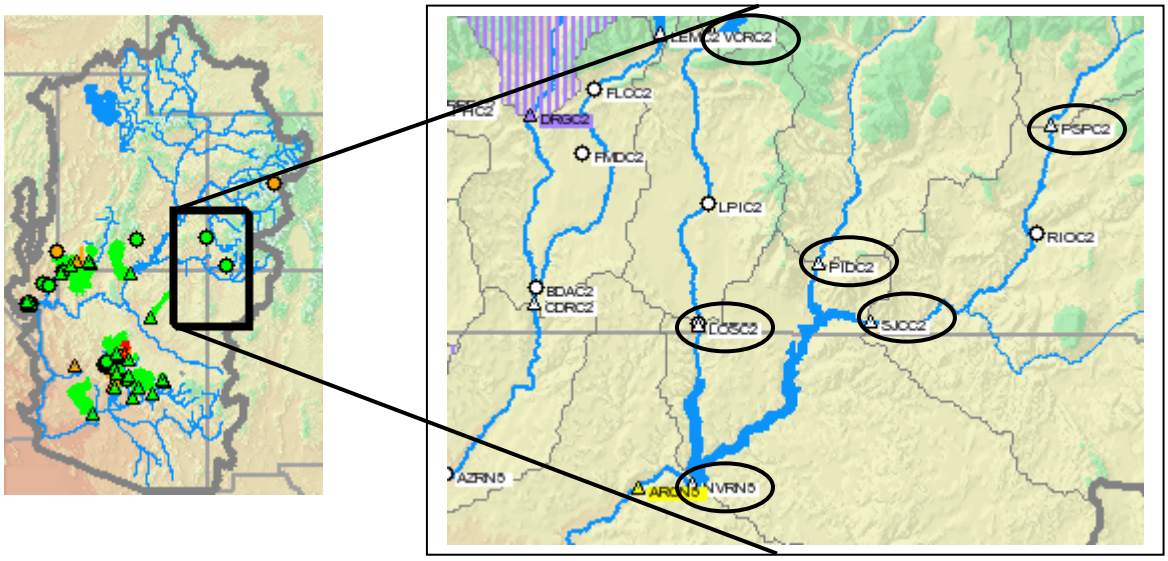

Figure 1: Study area in southwestern Colorado with forecast points circled in black.

Two models were calibrated in this study: the Sacramento Soil Moisture Accounting Model (SAC-SMA) (Burnash, et al., 1973) and the Snow Accumulation and Ablation Model (SNOW-17) (Anderson, 1973). The SAC-SMA uses two layers to account for flow: an upper zone and a lower zone. Of the 13 parameters optimized in the SAC-SMA, seven pertain to the upper zone, and six to the lower zone. The SNOW-17 model is the primary snow accumulation

and ablation model for the NWS, and models the energy exchange at the snow surface, heat storage and heat deficit within the snowpack, liquid water retention and transmission through the snowpack, and heat exchange at the ground surface (Anderson, 1973). A total of 16 parameters (13 SAC-SMA and 3 SNOW17) for each level of the multi-tiered basins were optimized using an adapted version of the MACS procedures. Including the seven SAC-SMA parameters pertaining to the upper zone, there are a total of ten parameters (including the three SNOW17 parameters) which influence the upper soil layers and six parameters which influence the lower zones processes. A set of manually calibrated parameter values was provided by the CBRFC. After the MACS optimizations, the final parameter sets, resulting model simulations, and error statistics were compared. The MACS used the RFC parameter bounds based on predetermined limits from the CBRFC's research.

The MACS optimization procedure used in this study was developed to overcome single-step, single-criteria approaches, using a step-by-step process, utilizing LOG or DRMS criteria to emphasize the different parts of the hydrograph throughout the calibration process. MACS was designed to mimic the manual calibration procedures of the NWS RFC hydrologists and was developed in conjunction with the North Central River Forecast Center (NCRFC). There is a basic three step approach to the general automatic calibration scheme.

Step 1: All parameters (16 in a single tier or level) are optimized using a LOG criterion. This *first step* places strong weighting on the low-flow portions of the hydrograph and gives good estimates of the lower zone parameters. However, by computing the criterion over the entire hydrograph and optimizing all of the parameters, this step also helps to loosely constrain the remaining (upper zone) model parameters into the region that provides coarse fitting of the peaks.

Step 2: The *second step* of MACS emphasizes the estimation of parameters that influence higher flow events. Lower zone parameters estimated in the first step are held constant, and a second optimization is run using the DRMS function using the upper zone parameters.

Step 3: Once parameters are obtained in step two, *step three* is run using the LOG function to fine-tune the lower zone parameters. Once the optimized values are obtained for the parameters, the modeler may fine-tune the estimates manually using local expertise and knowledge of the system.

The current limitations on the OPT3 program allows for calibration of up to 48 parameters at one time (this is limitation is currently being addressed). During the initial stages of this study, however, there was a 32-parameter limit on the OPT3. As a result, only the third of the three different MACS approaches applied utilizes the simultaneous optimization of all 48 chosen parameters (16 for each level on the three-tiered basins). For all three methods, RFC values were used for those parameters not calibrated with MACS. The Shuffled Complex Evolution (SCE-UA) included within the NWSRFS, was utilized as the search algorithm within the MACS procedure. The breakdown of the MACS methodology for each of the three different approaches and the fourth fine-tuning process is briefly outlined below.

MACS 1: The Six Step Approach

This method groups the upper and middle tiers for calibration, optimizing these tiers during the first three steps. The lower tier is then calibrated for the final three steps. Parameters not initially optimized are set to mid-range values.

MACS 2: The Area Method

Each tier is run separately for calibrations during this nine step approach. The tiers are calibrated according to area with the largest area being calibrated first. Parameters not initially optimized are set to mid-range values.

MACS 3: The Three Step Method

This procedure attempts to optimize all 48 parameters at once in a three step process.

MACS Fine-Tuning Method

As an additional correcting mechanism, the fourth approach, a fine-tuning process, further tightens the parameter values which were previously calibrated. This procedure utilized the RFC manually calibrated parameters and attempted to fine-tune or adjust them to potentially improve simulations. The upper and lower parameter ranges for each level of each sub-basin are set by increasing/decreasing the RFC value by 20 percent. Three criteria were tested for use in fine-tuning: LOG, DRMS, and MVRMS (monthly volume RMS).

Each basin was calibrated for a ten year period spanning from October 1978 to September 1988. Parameters were then evaluated over the entire period of record available. Statistics were evaluated for the period, including percent bias (% Bias) and DRMS, monthly percent biases, and flow interval percent biases.

2.2 Summary of Findings

An overview of results are presented here; more detailed findings are presented in the reports and publications listed below. Based on the basins and procedures tested in this study, the three initial methods (MACS1, MACS2, and MACS3) perform similarly overall (%Bias and DRMS), but have slightly different performances seasonally and over the various flow groups for the basins in the San Juan system. The MACS 1 (Six Step Approach) appears to provide calibrations most similar to the RFCs. It also has lower monthly and flow group biases, on average. In general, MACS 3 (Three Step Approach) appears to have a higher flow group and monthly percent bias than the other two methods. However, all three methods do produce parameter estimates in a timely and efficient manner resulting in optimizations similar in quality to the manual calibrations currently in use.

The fine-tuning mechanism (MACS4) tested in this study helped broaden the scope for future implementation of MACS for basins which have been preliminarily calibrated. With the one-step, single-criterion, 48 parameter calibration procedure the MACS fine-tuning processes allowed for satisfactory results in a relatively short period of time (~1 hour). For the most part, the DRMS criteria provided the lowest DRMS and percent bias errors, closely followed by the

MVRMS. The LOG criterion tended to result in higher percent biases in most cases, leaving it less desirable as a fine-tuning criterion.

The results presented in this study provide evidence that the MACS procedure, when adapted to the watershed system under study, can meet the need for an automatic calibration system to assist or complement manual calibration procedures. Automated procedures are timely and provide consistent, reliable results. The NWS RFC hydrologists from the CBRFC have also implemented MACS for several watersheds which had previously been manually calibrated. Results to date have been satisfactory for the basins studied.

3. Benefits and Lessons Learned – Operational Perspective

Current and potential benefits which have occurred from this cooperative research project include:

- Training and interest in optimization and calibration procedures by CBRFC hydrologists
- Use of UCLA personnel as a resource to implement automated procedures within CBRFC
- Successful use of automated procedures within CBRFC by hydrologists.
- Comparable and encouraging results for use of the automated procedures as a tool for tweaking and improving existing calibrations of forecast points
- Training manual and report on automated optimization procedures for use within the RFCs (forthcoming)

4. Benefits and Lessons Learned – University Partner

Benefits which have been gained through this research project include:

- Training of a UCLA undergraduate student on NWSRFS and hydrologic modeling theory
- Exposure of undergraduate to operational hydrology and forecasting through discussions with CBRFC hydrologists
- Training and education to CBRFC hydrologists on optimization theory and previous NWS work
- Positive collaboration and interaction with CBRFC hydrologists, allowing for a better understanding of operational problems in calibration of forecast basins and data issues and requirements
- Publications and presentations on optimization and calibration procedures developed in conjunction with NWS personnel
- Further collaborations with NWS hydrologists involving burn hydrology and potential forecasting and modeling problems (and estimation of parameters) on burned watersheds.

5. Publications and Presentations

Publications:

Hogue, T.S. and E. Aghnami, 2005: Parameter Estimation for multi-level watersheds in the Colorado River basin, *to be submitted*, *American Water Resources Association.*

Aghnami, E., and T.S. Hogue, 2005: Development of an Automatic Calibration Scheme for NWS Multi-level Watersheds, *Technical Report*, Department of Civil and Environmental Engineering, University of California, Los Angeles, September, 2005.

Hogue, T.S., Gupta, H., and S. Sorooshian, 2005: A "User-Friendly" Approach to Parameter Estimation in Hydrologic Models, *in press, Journal of Hydrology*.

Aghnami, E., and T.S. Hogue, 2005: Development of an automatic calibration scheme for multi-level watersheds in the Colorado River basin, Preprint: Symposium on Living with a Limited Water Supply, AMS Annual Meeting, January 9-13.

Presentations:

Development of an automatic calibration scheme for multi-level watersheds in the Colorado River basin, Poster presentation, Living with a Limited Water Supply, AMS National Meeting, San Diego, CA, January, 2005.

Developments in Optimization Techniques and Application to Hydrologic and Land-surface Modeling, Department of Civil and Environmental Engineering, University of Southern California, April 30, 2004

Advancements in Modeling and Tools for Hydrologic Forecasting, CEA-CREST (NSF Center for Environmental Analysis-Centers of Research Excellence in Science and Technology) and the Department of Geosciences, California State University, Los Angeles, February 19, 2004

Recent Developments in Automatic Calibration and Application to Hydrologic Modeling, Southern California Academy of Sciences Annual Meeting, Long Beach, CA, May 14th.

6. Summary of University/Operational Partner Interactions and Roles

Throughout the length of the project, UCLA and the CBRFC maintained active collaborations including discussions between the PIs, data exchange, troubleshooting and UCLA guidance to the CBRFC on implementation of optimization procedures within the operational setting. UCLA completed an in-house extensive development and comparison of calibration approaches for the San Juan Forecast Group in the CBRFC and is in the process of completing a journal article and specific technical report for the RFCs. Results of this study will be presented to the CBRFC at the "Research to Operations" meeting being held in early October in Park City, Utah (http://www.wrh.noaa.gov/hydroscience/index.php). In consultation with UCLA, CBRFC tested the optimization procedures at selected forecast points. The CBRFC also used automated procedures to fine-tune or tweak some of previous manual calibrations, especially to on basins where parameters were more difficult to estimate. The CBRFC also provided data sets and early guidance on troubleshooting of NWSRFS models and procedures. The existing collaboration has provided a solid foundation for on-going and future projects, including the investigation of post-burn modeling parameter estimation and hydrologic forecasting. Through collaborations with the western region of the NWS and the CBRFC, the PI has also started collaborations with the USGS/NWS Debris Flow Task charged with improving flash flood prediction in the western United States.